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SEMICONDUCTOR MILLIMETER AND CENTIMETER WAVE RADIOMETER FOR THE STUDY OF THE RADIATION OF AN UNDERLYING SURFACE

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16. Abstract

A theoretical and experimental investigation of a superheterodyne radiometer system with input frequency converter and intermediate frequency modulation is presented. Conditions are found, at which the temperature sensitivity of the device does not deteriorate. A sensitivity function to external parameters (temperature, heterodyne power) of a radiometer system with intermediate frequency modulation and a Schottky diode frequency converter is presented and calculated. Use of a frequency converter at the second harmonic of the heterodyne permitted simplication of the radiometer design and the use of a semiconductor heterodyne. A 3 cm range intermediate frequency amplifier permitted the use of centimeter wave radiometer signals. Fluctuation sensitivity of radiometers with a 1 sec time constant is 0.3 K at 3.4 mm and 0.06 K at 3 cm.

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Annotation

A theoretical and experimental investigation of a superheterodyne radiometer system, with input frequency converter and intermediate frequency modulation, is carried out in the study. Conditions are found, under which the temperature sensitivity of the device does not deteriorate. For this purpose, a sensitivity function to external parameters (temperature, heterodyne power) is presented and calculated, of a radiometer system with intermediate frequency modulation and a Schottky diode converter.

The use of a frequency converter at the second harmonic of the heterodyne permitted simplification of the radiometer design and use of a semiconductor heterodyne. A 3 cm range intermediate frequency amplifier permitted the use of centimeter wave radiometer signals. The fluctuation sensitivity of radiometers with a 1 sec time constant is 0.3 K at 3.4 mm and 0.06 K at 3 cm.

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Study of the microwave radiation of underlying surfaces shows the promise of radiophysical methods for determination of their characteristics [1]. In this case, the simultaneous use of two or more frequencies is most effective. This permits isolation of the contribution of atmospheric formations [1, 2]. A combination of centimeter and millimeter ranges is of interest, since centimeter radiometers have high temperature sensitivity (on the order of hundredths of a degree [3]), and millimeter waves are sensitive to water vapor and cloud cover. /3*

Much attention has been given in recent years to the development of millimeter superheterodyne receivers [4, 5]. The noise temperature of a stationary receiver at frequencies of 80-120 GHz achieved 500 K [6]. Aircraft radiometers have been developed, for the detection of traces of petroleum, measurements of the thickness of ice cover, etc., at a frequency of 90 GHz [7].

However, the classical layout of a modulation superheterodyne radiometer in the shortwave section of the millimeter wave range does not permit the limiting characteristics to be obtained, because of considerable losses in the input circuit and the lack of uncoupling devices. An attempt to solve this problem by the use of a Schottky diode in the frequency converter is presented in [8, 9], and it consists of shifting the modulation to an intermediate frequency. This method appears to be promising and to require further development, for the following reasons. /4
First, shortening the input circuit decreases the losses in it, which are extremely significant at frequencies of hundreds of gigahertz (they can degrade the radiometer sensitivity twofold or more). Second, elimination of the mechanical modulator simplifies the input circuit, increases reliability and eliminates vibration at multiple frequencies of the modu-

*Numbers in the margin indicate pagination in the foreign text.

lation frequency. Third, because of the lack of uncoupling devices modulation at the input can result in the development of stray modulation of the intrinsic noise and power of the heterodyne. On the contrary, with intermediate frequency modulation, because of the presence of industrial ferrite elements, stray modulation is excluded easily.

A theoretical and experimental investigation of a radiometer system, with intermediate frequency modulation and a Schottky diode harmonic frequency converter is carried out in this study, in order to produce a sensitive and reliable device.

<u>Radiometer System with Intermediate Frequency Modulation</u>

The fluctuation sensitivity of a superheterodyne radiometer with input frequency converter can be presented in the form

$$\delta T_{rad} = K \frac{L(T_{n.ifa} + T_{out})}{\sqrt{\Delta f \cdot \tau}} = L \, \delta T_{ifa} , \qquad (1)$$

where $T_{n.ifa}$ is the noise temperature of the intermediate frequency amplifier, T_{out} is the noise temperature at the frequency converter output, Δf is the radiometer frequency band, τ is the time constant of the RC circuit output, K is a coefficient determined by the nature of the modulation and demodulation, δT_{ifa} is the fluctuation sensitivity of the radiometer at the intermediate frequency and L is the conversion losses.

A characteristic of the intermediate frequency modulation radiometer /5 is the possibility of the development of a false signal with change in operating conditions of the frequency converter. This leads to deterioration of the temperature sensitivity of the system and an equivalent deterioration in sensitivity of the intermediate frequency radiometer. In this case, expression (1) can be written in the form

$$\delta T_{rad} = L\,(\delta T_{out} + \Delta T_{out.ifa}) . \qquad (2)$$

Here, $\Delta t_{out.ifa}$ is the change in output noise temperature of the frequency converter at the modulator input, as a result of the changed external parameters (the basic factors affecting the frequency converter: heterodyne power, physical temperature of nonlinear element (NE), bias voltage).

It is evident that the temperature sensitivity of the system does not deteriorate, if

$$\Delta T_{out.ifa} < \delta T_{ifa} . \qquad (3)$$

We express the quantity $\Delta t_{out.ifa}$ by the derivatives of the output noise temperature of the frequency converter. With change in heterodyne voltage (U_h) and a finite resistance of the bias source,

$$\Delta T_{out}^{(u_h)} = \frac{\partial T_{out}}{\partial u_h} \Delta u_h + \frac{\partial T_{out}}{\partial u_{cm}} \Delta u_{cm} \qquad (4)$$

and, similarly, for the case of the effect of the physical temperature (T),

$$\Delta T_{out}^{(T)} = \frac{\partial T_{out}}{\partial T} \Delta T + \frac{\partial T_{out}}{\partial u_{cm}} \Delta u_{cm} . \qquad (5)$$

Here, ΔU_{cm} is the bias voltage increment.

In the actual layout of an intermediate frequency modulation radiometer system (Fig. 1), the frequency converter output is connected to a transmission line with a specific wave resistance Z_o and, then, through uncoupling gates B_1 and B_2, to the modulator input. On consideration that, initially, the converter output and the transmission line are /6
matched, for the noise temperature increment at the intermediate frequency amplifier input, we have (we disregard the losses in the gates)

$$\Delta T_{out.ifa} = \Delta T_{out} - T_{out} \Delta \Gamma + T_{gate} \Delta \Gamma , \qquad (6)$$

where $\Delta \Gamma$ is the change in power return loss of the intermediate frequency signal, T_{gate} is the physical temperature of gate B_1.

The following can be written for the return loss increment

$$\Delta \Gamma^{(U_h)} = \frac{\partial \Gamma}{\partial U_h} \Delta U_h + \frac{\partial \Gamma}{\partial U_{cm}} \Delta U_{cm} \quad , \tag{7}$$

$$\Delta \Gamma^{(T)} = \frac{\partial \Gamma}{\partial T} \Delta T + \frac{\partial \Gamma}{\partial U_{cm}} \Delta U_{cm} \quad . \tag{8}$$

By substituting (4, 5, 7, 8) in (6), we obtain the following expressions for the noise temperature increment at the intermediate frequency amplifier input with change in external parameters

$$\Delta T^{(U_h)}_{out.ifa} = \frac{\partial T_{out}}{\partial U_h} \Delta U_h + \frac{\partial T_{out}}{\partial U_{cm}} \Delta U_{cm} + (T_{gate} - T_{out})\left(\frac{\partial \Gamma}{\partial U_h} \Delta U_h + \frac{\partial \Gamma}{\partial U_{cm}} \Delta U_{cm}\right), \tag{9}$$

$$\Delta T^{(T)}_{out.ifa} = \frac{\partial T_{out}}{\partial T} \Delta T + \frac{\partial T_{out}}{\partial U_{cm}} \Delta U_{cm} + (T_{gate} - T_{out})\left(\frac{\partial \Gamma}{\partial T} \Delta T + \frac{\partial \Gamma}{\partial U_{cm}} \Delta U_{cm}\right). \tag{10}$$

Expressions (9, 10) substituted in (2) give formulas for the temperature sensitivity of the intermediate frequency modulation radiometer system.

It is evident that the optimum operating conditions of the system are those, under which

$$\frac{\partial T_{out.ifa}}{\partial U_h} = 0 \; , \qquad \frac{\partial T_{out.ifa}}{\partial T} = 0 \; . \tag{11}$$

However, in a number of cases, the derivatives may not have a 0 value, or they may be in regions, where it is difficult to obtain the input and output impedance values. Therefore, to estimate the effect of U_h and T instabilities at all points, a sensitivity function [10] can be introduced which, for this case, it is convenient to introduce in the form

$$S^{(U_h)} = \frac{\Delta T^{(U_h)}_{out.ifa}}{\left(\frac{\Delta U_h}{U_h}\right)} \; ; \qquad S^{(T)} = \frac{\Delta T^{(T)}_{out.ifa}}{\left(\frac{\Delta T}{T}\right)} \; . \tag{12}$$

With a given fluctuation of a radiometer intermediate frequency sensitivity (δT_{ifa}), knowledge of sensitivity function (12) permits determination of the permissible relative perturbations of the external parameters U_h, T $\Delta U_h/U_h = \delta T / S^{(U_h)}$; $\Delta T/T = \delta T_{ifa}/S^{(T)}$. /7

We find the analytic expressions of $S^{(U_h)}$ and $S^{(T)}$. ΔU_{cm} must be excluded from expressions (9, 10) for this.

Since, with change in heterodyne voltage, the bias voltage increment $\Delta U_{cm} = -R_{cm}\Delta I_o$ (where I_o is the rectified current), and

$\Delta I_o = \frac{\partial I_o}{\partial U_h}\Delta U_h + \frac{\partial I_o}{\partial U_{cm}}\Delta U_{cm}$; we obtain

$$\Delta U_{cm} = -\frac{R_{cm}\frac{\partial I_o}{\partial U_h}\Delta U_h}{1 + R_{cm}\frac{\partial I_o}{\partial U_{cm}}}, \qquad (13)$$

where R_{cm} is the internal resistance of the bias source.

By substituting (13) in (9) and then in (12), finally, we obtain

$$S_1^{(U_h)} = U_h\Big[\frac{\partial T_{out}}{\partial U_h} - R_{cm}\frac{\partial T_{out}}{\partial U_{cm}}\frac{\partial I_o}{\partial U_h}\Big/\Big(1 + R_{cm}\frac{\partial I_o}{\partial U_{cm}}\Big) +$$

$$+(T_{gate} - T_{out})\Big(\frac{\partial \Gamma}{\partial U_h} - R_{cm}\frac{\partial \Gamma}{\partial U_{cm}}\frac{\partial I_o}{\partial U_h}\Big/\Big(1 + R_{cm}\frac{\partial I_o}{\partial U_{cm}}\Big)\Big)\Big]. \qquad (14)$$

Similarly,

$$S^{(T)} = T\Big[\frac{\partial T_{out}}{\partial T} - R_{cm}\frac{\partial T_{out}}{\partial U_{cm}}\frac{\partial I_o}{\partial T}\Big/\Big(1 + R_{cm}\frac{\partial I_o}{\partial U_{cm}}\Big) +$$

$$+(T_{gate} - T_{out})\Big(\frac{\partial \Gamma}{\partial T} - R_{cm}\frac{\partial \Gamma}{\partial U_{cm}}\frac{\partial I_o}{\partial T}\Big/\Big(1 + R_{cm}\frac{\partial I_o}{\partial U_{cm}}\Big)\Big)\Big]. \qquad (15)$$

We note that the expression for $S_1^{(U_h)}$ is valid only with a fixed NE temperature. In the millimeter wave range, because of the use of extremely small working areas of the concentrated NE, their heating is possible due to the heterodyne power. Of course, with oscillations of /8

the power, a change in temperature of the working area will occur, which is not taken into account in [14]. Therefore, we obtain a more complete expression of $S^{(U_h)}$.

For the increment $\Delta T_{out.ifa}$, by definition, the following can be written (with a constant physical temperature),

$$\Delta T^{(U_h)}_{out.ifa} = \frac{S_1^{(U_h)}}{U_h} \Delta U_h . \tag{16}$$

On the other hand, if there is a change of T,

$$\Delta T^{(T)}_{out.ifa} = \frac{S^{(T)}}{T} \Delta T . \tag{17}$$

Since a change in physical temperature of the junction occurs in this case, which can be connected with the change in heterodyne voltage in the following manner

$$\Delta T = H \Delta U_h , \tag{18}$$

the resulting change of $\Delta T_{out.ifa}$, as a result of ΔU_h, has the form

$$\Delta T^{(U_h)}_{out.ifa} = \frac{S_1^{(U_h)}}{U_h} \Delta U_h + \frac{S^{(T)}}{T} H \Delta U_h \tag{19}$$

and the resulting sensitivity to heterodyne voltage

$$S^{(U_h)} = S_1^{(U_h)} + H \frac{U_h}{T} S^{(T)} . \tag{20}$$

Function H, which connects increments ΔT and ΔU_h, must be found in the latter expression. The problem of the steady state temperature of a point contact, formed by a metal needle and a semiconductor, was solved in [11]. The configuration of the system is shown in Fig. 2. The steady state temperature is given by the expression

$$T' = \frac{\frac{1}{2} P_s + P_1}{4 r \left(k_1 + k_2 \operatorname{tg} \frac{\theta}{2}\right)} ; \tag{21}$$

where P_s is the power dissipated in series resistor R_s, r is the radius of the contact, P_1 is the power dissipated in the barrier layer, k_1 and

k_2 are the thermal conductivity of the semiconductor and the contact spring, respectively, θ is the angle of the tip of the needle. /9

With P_s and P_1 vs. U_h known, function H in (20) can be determined,

$$H = \frac{1}{4\pi\left(k_1 + k_2 \operatorname{tg}\frac{\theta}{2}\right)}\left[\frac{1}{2}\frac{\partial P_s}{\partial U_r} + \frac{\partial P_1}{\partial U_r}\right]. \tag{22}$$

Functions $S_1^{(U_h)}$, $S^{(T)}$ and $S^{(U_h)}$ were found from the expressions presented, for a radiometer with a Schottky diode (SBD) frequency converter, with equal loads on the signal and image frequencies. The remaining combination frequencies are considered to be short circuited on the diode terminals. The methods of calculation of T_{out}, optimum signal generator resistance $R_{g.opt}$, the output resistance of the SBD frequency convertor and their derivatives are reported in [12]. Since the impedance of the signal generator in actual frequency converters is fixed, the derivatives of the output noise temperature were found as $\lim_{\Delta x \to 0}\left[T_2(R_{g\,opt\,1}; x_2) - T_1(R_{g\,opt\,1}; x_1)\right]/(x_2 - x_1)$. A model of a diode with variable barrier layer capacitance and modulation by the sinusoidal voltage of the heterodyne was adopted.

The results of calculation of the sensitivity function of a radiometer system, with intermediate frequency modulation and frequency converter on the first and second harmonics of the heterodyne of an ideal SBD, as a function of the diode rectified current, are presented in Figs. 3 and 4. In finding $S^{(U_h)}$, $S^{(T)}$ - R_{cm}, U_{cm} and $(T_{gate} - T_{out})$ were assumed to be zero. The temperature of the input load of the frequency converter was assumed to be 290 K.

There are considerably higher absolute values of the sensitivity function in the presence of stray diode parameters. The results of calculations for the ratio $\omega/\omega_{pr} = 0.1$ (ω is the signal frequency, $\omega_{pr} = 1/R_s C\delta$), are presented in Figs. 5 and 6. The cases of constant and variable barrier capacitance are compared. It is evident that the sensitivity increases with a variable barrier capacitance. For example, in conversion at the first harmonic with $U_{cm} = 0 - |S_1^{(U_h)}|$, it is /10

approximately three times greater than for the case of a constant capacitance. A direct bias input (Fig. 7, 8) decreases the difference. In conversion at the second harmonic, the effect of the variable capacitance is not significant.

Curves of sensitivity to the heterodyne voltage are presented in Fig. 9, with account taken of heating of the junction of a gallium arsenide diode, for contact diameters 0.5, 2 and 5 μm, as well as without heating taken into account (dashed line). Constant thermal conductivities were used: for gallium arsenide, $k_1 = 40$ W/m·K; for the metal needle, $k_2 = 160$ W/m·K. The calculations were carried out for a frequency converter on the second harmonic of the heterodyne. For all other cases, the percent change of $S^{(U_h)}$ proves to be approximately the same. Noticeable deterioration of $S^{(U_h)}$ is observed, for contact diameters less than 1 μm and rectified currents greater than 5 mA.

It is evident that $S^{(U_h)}$ and $S^{(T)}$ are determined by both the properties of the frequency converter and the external parameters, such as T_{back}, R_{cm} and T_{gate}. Consequently, it is possible to reduce the sensitivity, by selection of optimum values of T_{back}, R_{cm} and T_{gate}. It evidently is not always convenient to regulate T_{back}, since a noise signal must be introduced into the input circuit. This increases the losses in it and complicates the system. The difference $(T_{out}-T_{gate})$ can be changed within certain limits but, as the calculations show, this quantity has a negligible effect on $S^{(U_h)}$. We dwell on the possibility of minimization of S, by means of an automatic bias resistance.

Automatic compensation of drift of the output noise temperature is achieved, if the automatic bias voltage changes by the amount, at which $T_{out.ifa}$ remains constant.

An expression for the optimum automatic bias resistance, if $(T_{gate}-T_{out}) = 0$, is presented in 9 , /11

$$R_{cm\,opt}^{(U_h)} = \frac{\dfrac{\partial T_{out}}{\partial U_h}}{\dfrac{\partial I_0}{\partial U_h}\dfrac{\partial T}{\partial U_{cm}} - \dfrac{\partial I_0}{\partial U_{cm}}\dfrac{\partial T_{out}}{\partial U_h}} \qquad (23)$$

If $T_{gate}-T_{out}\neq 0$, $R_{cm.opt}$ can be found by making $S_1^{(U_h)}$ equal to zero,

$$R_{cm.opt}^{(U_h)}=\frac{\frac{\partial T_{out}}{\partial U_h}+(T_{gate}-T_{out})\frac{\partial \Gamma}{\partial U_h}}{\frac{\partial T_0}{\partial U_h}\frac{\partial T_{out}}{\partial U_{cm}}-\frac{\partial T_0}{\partial U_{cm}}\frac{\partial T_{out}}{\partial U_h}+(T_{gate}-T_{out})\left[\frac{\partial T_0}{\partial U_h}\frac{\partial \Gamma}{\partial U_{cm}}-\frac{\partial T_0}{\partial U_{cm}}\frac{\partial \Gamma}{\partial U_h}\right]}. \quad (24)$$

A similar expression can be obtained for $R_{cm.opt}^{(T)}$. In this case, the heterodyne voltage derivatives are replaced by the physical temperature derivatives.

By using expression (23), $R_{cm}^{(U_h)}$ and $R_{cm}^{(T)}$ were found (Figs. 10, 11). It is evident that both quantities have relatively low values and are close to each other in a number of cases.

We estimate whether S is critical to the selection of R_{cm} and the permissible deviations of this quantity. The results of calculation of the sensitivity to the heterodyne power are presented in Figs. 12 and 13, for various values of R_{cm} and conversion on the first and second harmonics of the heterodyne. It follows from the graphs that, in a number of cases, the automatic bias resistance value has a strong effect on sensitivity. Even with change in the resistance by single ohms, $S^{(Ur)}$ changes substantially, especially in conversion at the second harmonic.

Under some conditions, $R_{cm.opt}$ proves to have a negative value. It evidently is complicated to accomplish this. In this case, R_{cm} should be selected as 0, to obtain the minimum S. However, this is not always true. For example, in conversion at the first harmonic with U_{cm} = 0.6 V (see Fig. 12), with rectified currents > 7 mA, minimization is /12
achieved by selection of larger R_{cm} (with R_{cm} > 20 ohm, saturation occurs and $S^{(U_h)}$ is practically unchanged), while a negative value of R_{cm} is necessary for complete stabilization.

There also is interest in finding the required voltage stability of the bias source, since direct bias input frequently is used, to reduce the power input. Characteristic functions of the derivatives $\partial T_{out}/\partial U_{cm}$

are presented in Fig. 14, for voltage converters at the first and second harmonics of the heterodyne, from which the required U_{om} stability is determined, with a known intermediate frequency fluctuation sensitivity of the radiometer.

The study conducted gives an idea of the values of the sensitivity function of a radiometer system with intermediate frequency modulation to the heterodyne power and the physical temperature. A system with an ideal SBD frequency converter has the lowest sensitivity: $S_1^{(U_h)}$ = 10 - 40 K; $|S^{(T)}|$ = 50 - 250 K. The presence of stray diode parameters considerably increases the sensitivity. Thus, for ω/ω_{pr} = 0.1, $|S^{(U_h)}|$ reaches 700 K under some conditions, and $S^{(T)}$ reaches 400 K.

To eliminate the effect of changes of the physical temperature of the crystal, in the majority of cases, its absolute instability should not exceed the temperature sensitivity of the intermediate frequency radiometer in order of magnitude.

A decrease in the SBD junction diameters to 3 μm also does not result in a noticeable change of $S^{(U_h)}$, but junctions, the diameters of which are less than 1 μm, are subject to the effect of thermal heating by the heterodyne power.

The resistance in the bias source circuit has a strong effect on S. This permits minimization of the sensitivity of a superheterodyne rad- /13 iometer system with intermediate frequency modulation to perturbations of the external parameters, by selection of the appropriate conditions.

Features of System and Radiometer Characteristics

Based on the calculations reported, an experimental specimen of a superheterodyne radiometer was developed at a frequency of 89 GHz. A block diagram of the radiometer is presented in Fig. 15.

Frequency conversion in the 3.4 mm channel is carried out at the second harmonic of the heterodyne. Harmonic frequency converters were widely used in the 1960s [13], but there is the opinion that the conversion losses of such converters increase by an average of 6 dB with an

increase of 1 in the harmonic number. However, the calculations have shown that, for a SBD, in distinction from the previously used point contact diodes, the conversion losses of a frequency converter at the second harmonic is only ~1 dB poorer than in the case of conversion at the primary frequency [12]. Therefore, a SBD harmonic converter was used in the design described, and it permitted the use of a relatively low frequency heterodyne in semiconductor instruments [14, 15].

It is known that, in a number of cases, semiconductor generators have more noise, and that their power stabilization is difficult. These two factors are of great importance in an intermediate frequency modulation device. Nevertheless, the difficulties indicated were eliminated in the device described by relatively simple means. Curves of the sensitivity of the system to the heterodyne voltage $S^{(U_h)}$ were presented above (see Fig. 8). With a 0.6 V direct bias voltage and $\omega/\omega_{pr} = 0.1$, $S^{(U_h)}$ is not over 400 K. As a result, the heterodyne voltage instability should not be worse than $\delta T_{ifa}/S^{(U_h)}$. A parametric 3 cm range amplifier /14 was used in the first cascade of the intermediate frequency amplifier in this design, and the fluctuation sensitivity of a 3 cm radiometer, connected to the switch input (P_1) (see Fig. 15) is 0.05 K. With small changes in heterodyne power, $\Delta P_h/P_h \simeq 2\Delta U_h/U_h$, and the permissible heterodyne power instability for this case is 0.024%.

A simple and quite effective solution was the use of an automatic power regulation (APR) system, with a p-i-n attenuator, which permitted the necessary heterodyne power stability to be obtained. The principle of operation of the APR is comparison of the voltage at the control detector output (D_1), with a fixed reference voltage and out of balance signal output to the p-i-n attenuator. The electron system is made up of one field transistor (p-i-n attenuator current regulator) and a microcircuit (feedback amplifier). A D402 diode head was used in the detector. Without the use of special measures for temperature stabilization of the stabilitron which gives the reference voltage and the control detector, the relative heterodyne power instability proved to be ± 0.01 % in 20 minutes of operation under laboratory conditions. This permitted complete solution of the problem of heterodyne power stabilization.

The heterodyne noise was eliminated by the use of an ultrahigh intermediate frequency (9 GHz). It should be noted that, by conversion on the harmonics, the problem of heterodyne noise suppression is considerably simplified, since filtration is easier at lower frequencies. Besides, the frequency converter can be set in a mode with low conversion efficiency at the first harmonic of the heterodyne, which also decreases the noise. In particular, in the present study, the conversion loss at the first harmonic was 12 dB greater than in conversion at the second harmonic.

The design of the frequency converter is presented in Fig. 16. It is a waveguide cross, made of three waveguides. Signal input is through a 1.2mm x 2.4mm cross section waveguide and, then, through a transforming junction by a 0.4mm high waveguide. A diode is formed, by means of advancing a pin with the contact needle. The semiconductor is soldered to an insert, to which voltage is furnished from the direct bias source. The heterodyne signal input is through a waveguide, with a 2.6mm x 5.2mm cross section input and a 0.4mm x 5.2mm cross section junction. The converted intermediate frequency signal is fed, through low frequency filters, to a coaxial waveguide junction, and it propagates through a 2mm. x 23mm cross section intermediate frequency waveguide. Circuit tuning is carried out with three short circuit plungers. The experimental value of the conversion loss in single band reception was 8 dB. The resulting conversion losses were a total of 2.5 - 3 dB poorer than the best results obtained for a first harmonic frequency converter [6]. By means of a high frequency filter installed at the frequency converter input, it was determined that single band reception is obtained. Suppression of the image frequency was achieved by shifting it to a frequency region, which is nearly beyond the limits of the signal waveguide, and it is required to assist in interpretation of the data obtained by means of a radiometer with a considerable separation of the signal and image frequencies. /15

The modulator (intermediate frequency) is made of a p-i-n diode. The first intermediate frequency amplifier cascade is a degenerate parametric amplifier, with a noise temperature ∿100 K and a 13 dB gain. The second, third and fourth cascades of the intermediate frequency amplifier are tunnel diode amplifiers 3 . The total gain of the

intermediate frequency amplifier is 52 dB and the transmission band is ~1 GHz.

Switch P_1 permits reception of the radiometer signal at two frequencies: 1. converted from 3.4 mm; 2. directly at the intermediate frequency. /16

The radiometer channels are calibrated with semiconductor noise generators NG_1 and NG_2. In calibrating the 3 mm channel, the calibration signal is fed through the heterodyne circuit. This simplifies the input circuit and reduces losses in it.

The required temperature stabilization of the frequency converter is found from the curves of system temperature sensitivity $S^{(T)}$ (see Fig. 8). In this case, with U_{cm} = 0.6 V, the maximum absolute value of $S^{(T)} \sim 400$ K and, for δT_{ifa} = 0.05 K, T = 290 K, the absolute instability of the physical temperature is 0.04 K. Since it is neccesary to stabilize a space where there is no significant heat emission, solution of this problem causes no difficuties.

The measured fluctuation sensitivity of the radiometer ΔT_{rad} in single band reception, with an output low frequency filter time constant in the form of a RC circuit of 1 sec, is 0.3 K, for λ = 3.4 mm and 0.06 K for λ = 3 cm.

The radiometer described was installed in a laboratory aircraft, in order to study the characteristics of the underlying surface. A recording of variations of the 3.4 mm radio brightness temperature , during flight over the surface of the sea, is presented in Fig. 17. The zero line, which shows the stability of operation of the radiometer, is noted by the number "0." After preliminary heating, the zero drift of the radiometer in an hour of continuous operation was not more than the fluctuation sensitivity of the 3 cm radiometer.

Under flight conditions, the temperature sensitivity of the radiometer deteriorated somewhat. A recording of the radio brightness temperature at 3.4 mm, in flying over a water-land boundary [1-3] is presented in Fig. 18. It permits determination of the sensitivity of

the device to natural sources of radio emission ($\tau = 1$ sec, connection to the load input at T = 280 K is noted by the number "0"). The sensitivity in the millimeter channel was 0.4 K and, in the centimeter channel, 0.07 - 0.08 K. /17

Thus, the use of intermediate frequency modulation and signal conversion at the second harmonic of the heterodyne permitted the development of a sensitive, reliable superheterodyne radiometer. With the development of shortwave semiconductor generators, ferrite decouplers and small loss modulators, the system used for constructing the radiometer system remains promising, since it can be shifted to higher frequencies.

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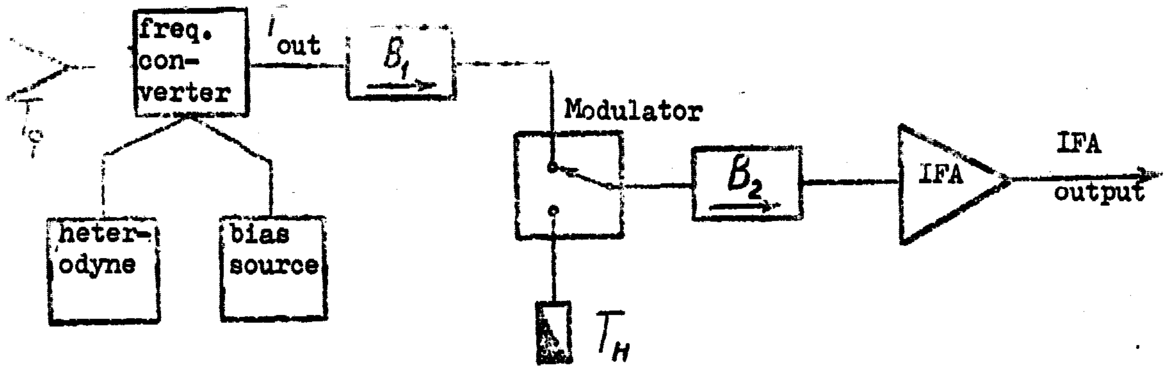

Fig. 1

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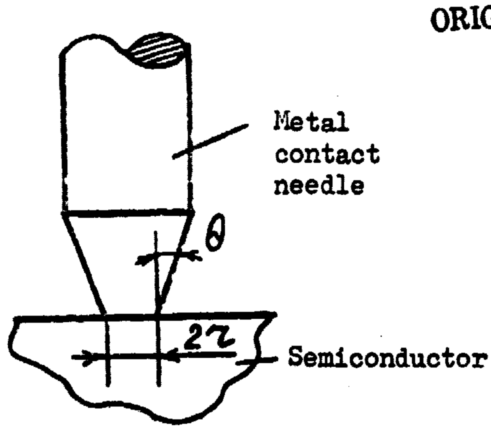

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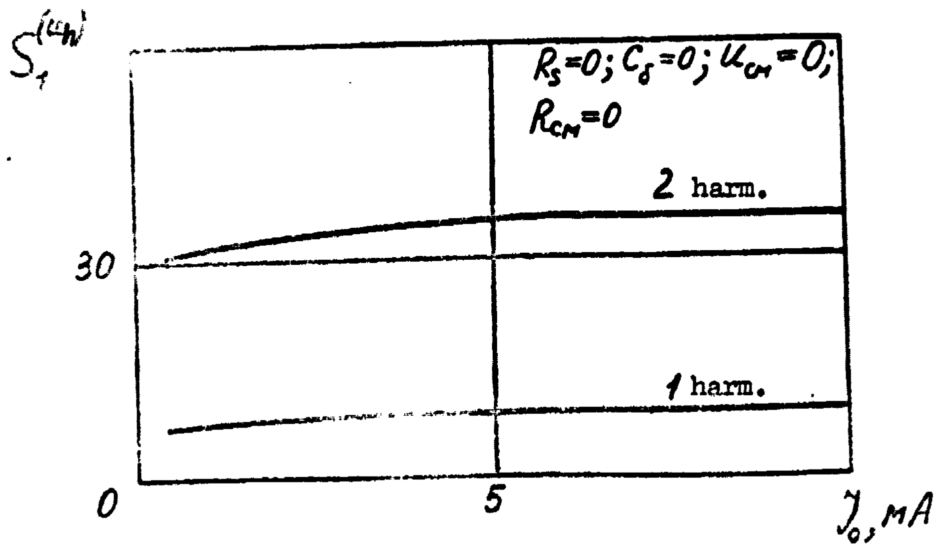

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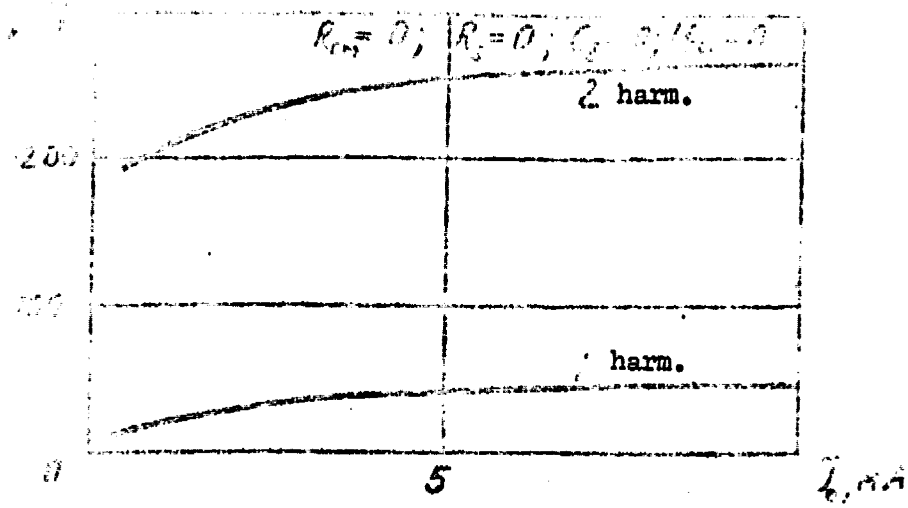

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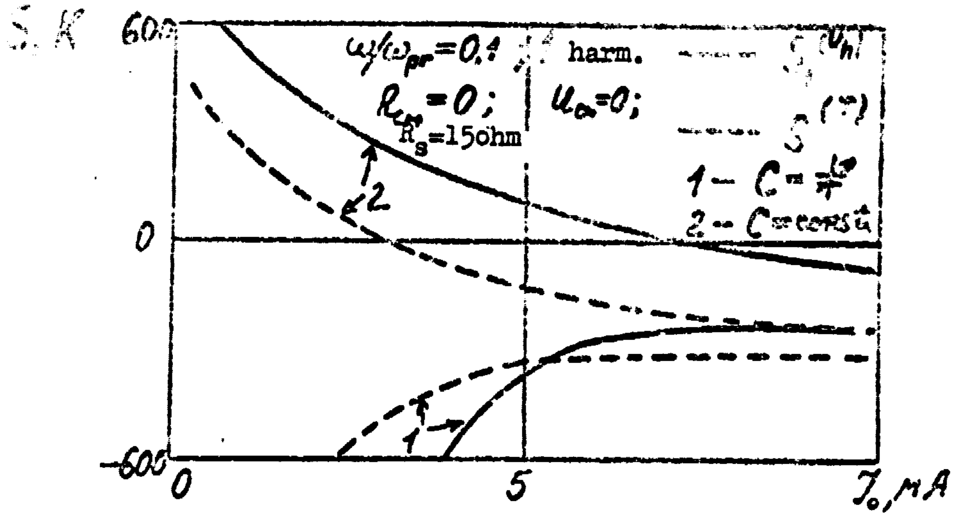

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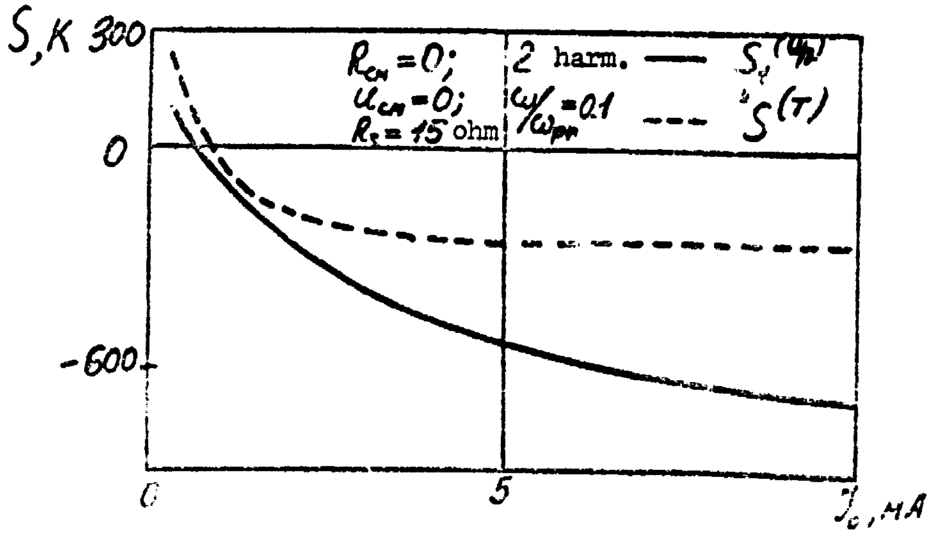

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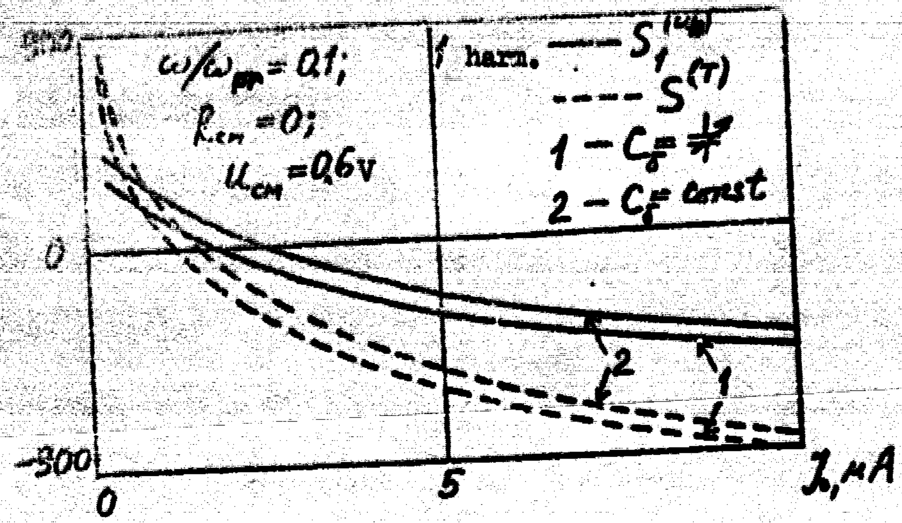

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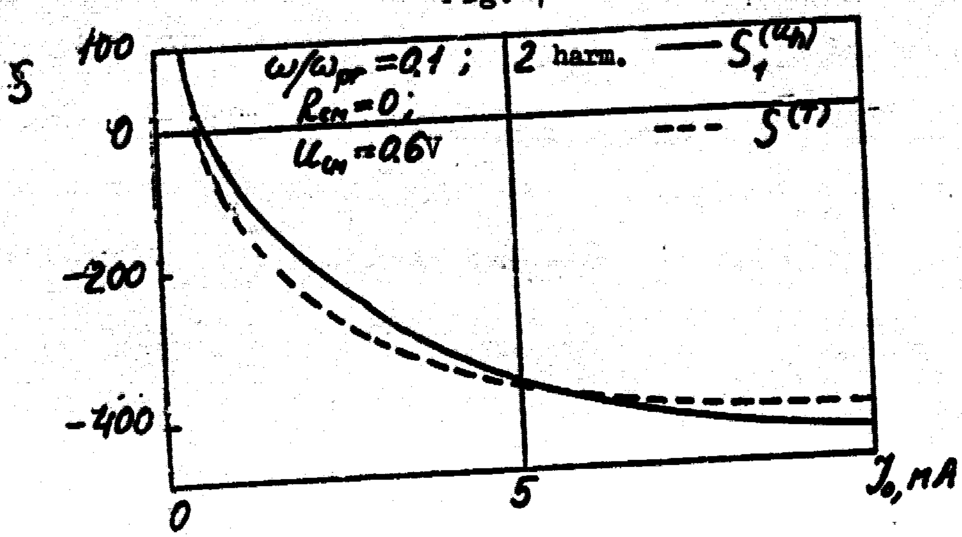

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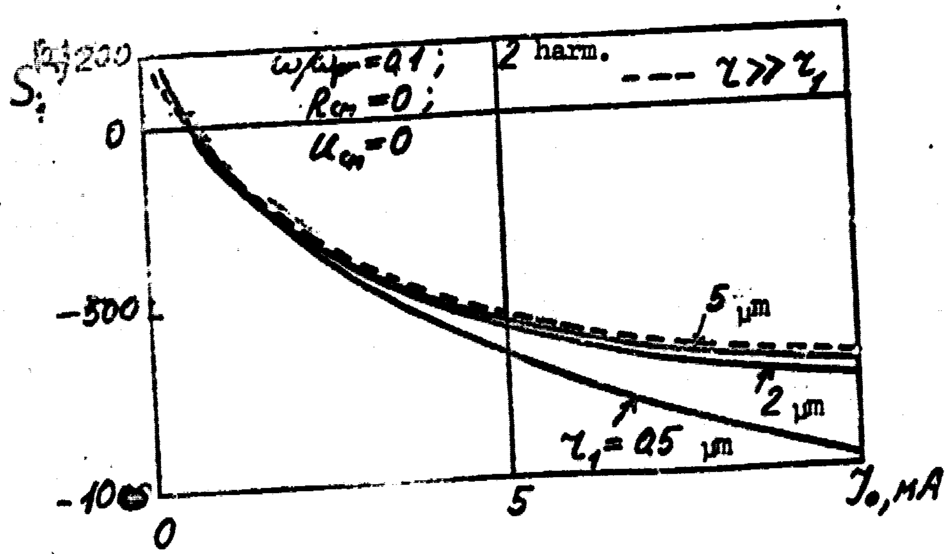

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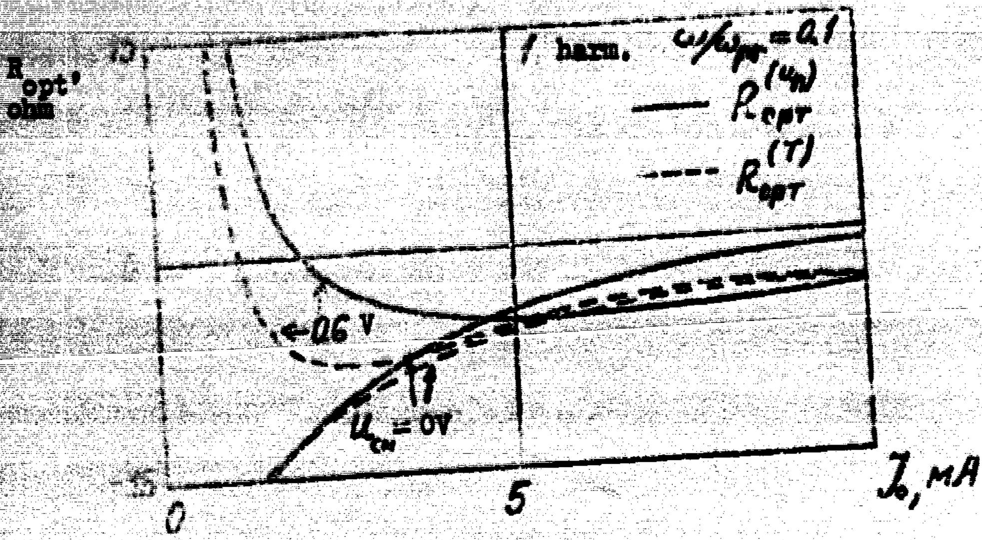

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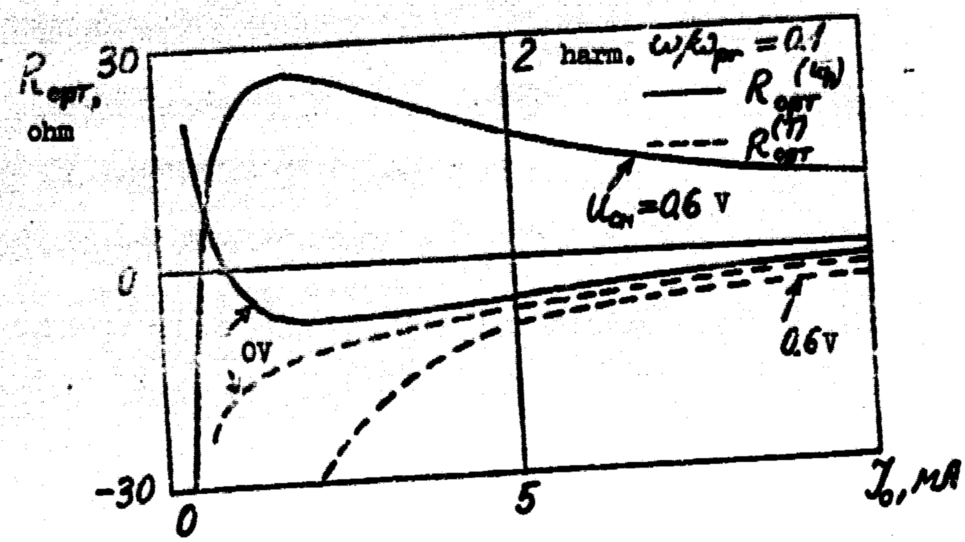

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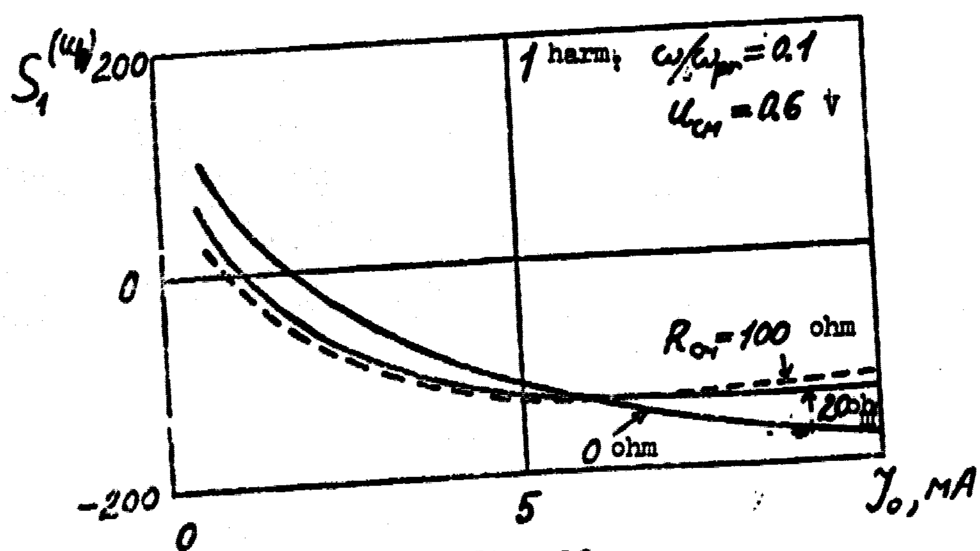

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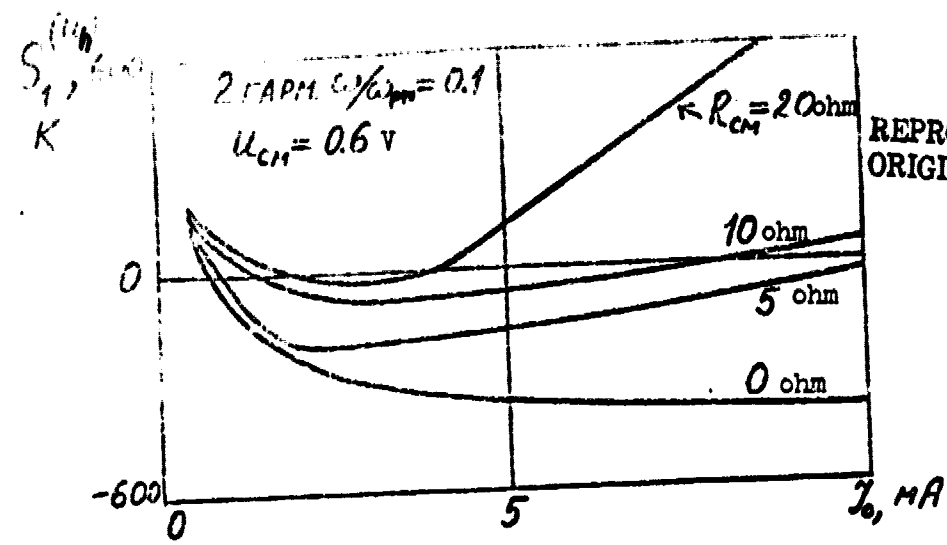

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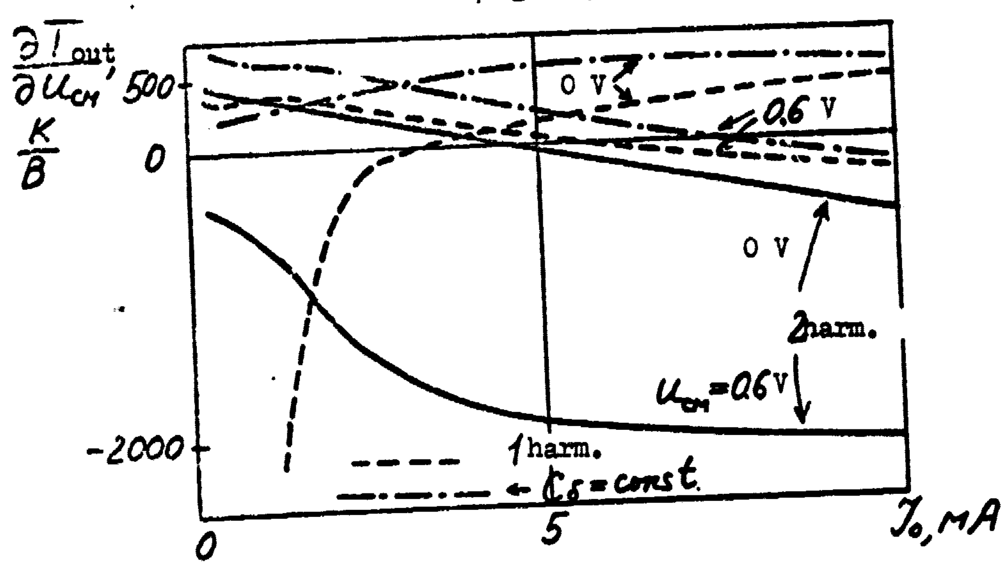

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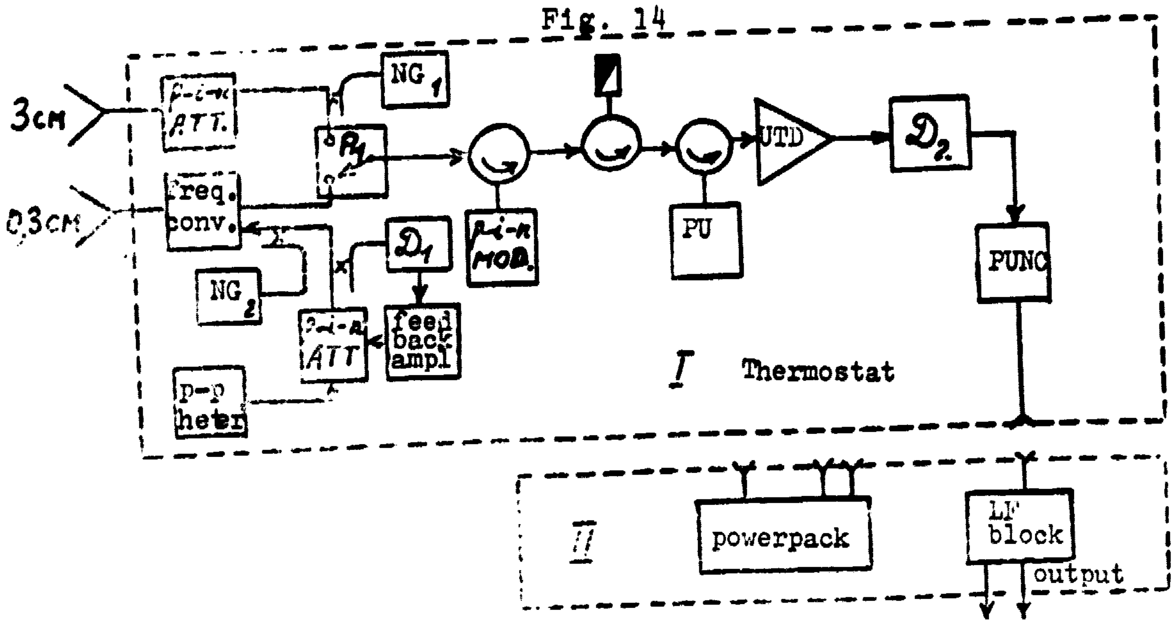

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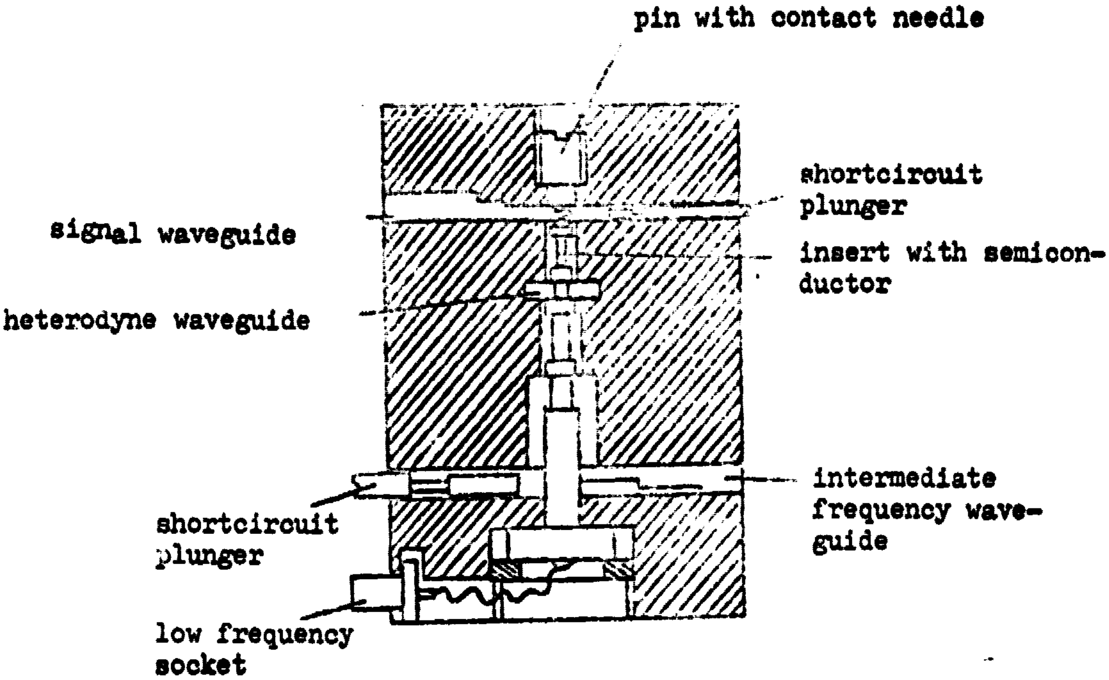
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shortcircuit plunger
signal waveguide
insert with semiconductor
heterodyne waveguide
intermediate frequency waveguide
shortcircuit plunger
low frequency socket

Fig. 16

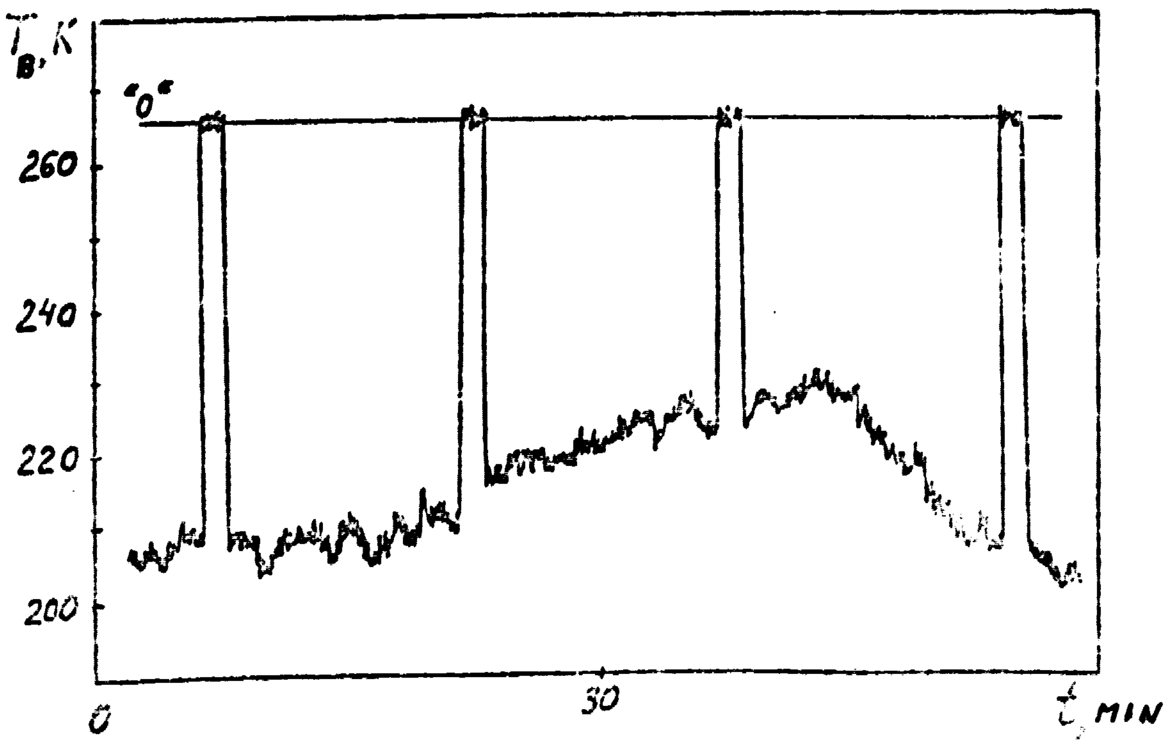
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Fig. 17

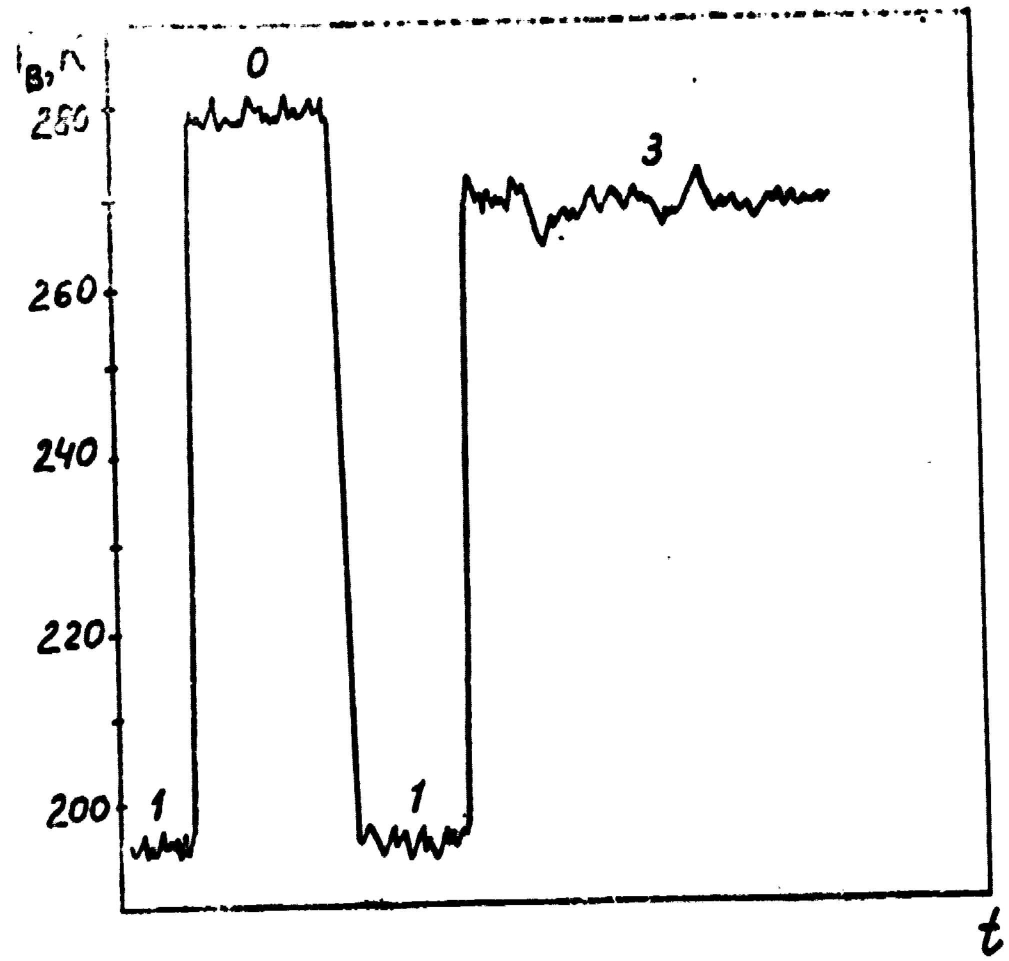

Fig. 18